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SANTA BARBARA, CALIFORNIA

INVESTIGATION OF MATERIALS FOR THE LOW FREQUENCY TELESCOPE EXPERIMENT

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ASTRO RESEARCH CORPORATION
SANTA BARBARA, CALIFORNIA

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INTERIM REPORT

INVESTIGATION OF MATERIALS FOR THE LOW FREQUENCY TELESCOPE EXPERIMENT

SUMMARY

Properties and other important characteristics of candidate materials for the LOFT have been extracted from the literature and are presented in individual data sheets. This investigation will continue with further compilation of this information and the development of criteria for selecting from among these materials, as the design of the Low Frequency Telescope progresses. In this report only the reflector net, tensioning tapes and lattice compression column are considered. The influence of the material properties and characteristics on the design is discussed.

INTRODUCTION

The selection of appropriate construction materials is of vital concern in the design and manufacture of the Low Frequency Telescope (LOFT) structure which must function reliably and efficiently in its space environment. The LOFT, with its unique requirements for large area deployment, antenna performance, and extended service life, presents a number of special materials-selection problems in addition to many which are common to other structures designed for space missions. Of special importance are:

(1) The need for data which will define dimensional changes resulting from long term exposure to the space environment of near-earth orbits;

(2) The need for data on the effects of creases on those materials proposed for use as tensioning and reflecting tapes;

(3) The need for suitable tubing and tape materials of dimensional forms suitable for minimizing micrometeoroid fracture rates throughout the five year mission.

Much of the information required is not available from the literature and it is anticipated that special test and analysis programs will be established as part of the LOFT program.

As part of the LOFT Experiment program, a search of the literature was begun for candidate materials of reasonable availability which could justifiably be considered for use as antenna components. The components for which the screening of materials was begun are:

(1) The reflecting net and rim mass
(2) The mast longerons and cross-members
(3) The tension tapes
(4) The mast diagonals

Electronic components and accessory hardware not presently defined in the design were excluded.

Pertinent data on mechanical and physical properties, environmental and fabrication characteristics were extracted from the literature for those materials which were judged to be suitable candidates for use as antenna components. This information was compiled in the form of individual data sheets for each material/component system considered and appears as Appendix A of this report. The importance of each of these types of pertinent data is discussed in the body of this report.

The final selection of materials from among these candidates will depend upon selection criteria that are under development. These criteria will include the effects of the materials selected on the overall structural efficiency, reliability and cost-effectiveness quotient of the program. The present data will be parameters in the formulation of those criteria as discussed later.

Early in the program it became evident that the volume of information required for selection of the most efficient materials was so great that the present effort could be considered only as an initial step. Many new aerospace materials will undoubtedly be ideally adapted to use in the antenna as manufacturing technology and engineering properties information are acquired. Other materials are probably well defined but continuing effort is required to explore the multitude of information sources available.

DESCRIPTION OF MATERIAL DATA SHEETS

In reviewing the literature, pertinent information for the contending candidates was extracted and assembled in individual data sheets. These are presented in Appendix A of this report. Data sheets are not yet prepared for some candidate materials. Data on other materials is not presented because they were considered not to be contenders. However, the reasons for some of these disqualifications are discussed in the following sections. The entire group of candidates originally considered in the materials selection program plan is listed below.

(1) Aluminum and aluminum coatings

(2) Mylar* (and metal composites)

(3) Kapton* (and metal composites)

(4) Kapton* (and boron composites)

(5) Stainless steel

(6) Steel (and aluminum composites)

(7) Silver (coatings)

(8) Beryllium

(9) Invar

(10) Temperature control coatings

(11) $A\ell_2O_3$ (on aluminum substrates)

(12) Boron

(13) Silicon carbide (and other ceramics)

(14) Titanium

(15) Magnesium

(16) Fiber reinforced (metallic, SiO_2) aluminum

(17) Fibrous glass (aluminum coated)

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(18) Fibrous quartz (aluminum coated)

(19) PBI resins and coatings

(20) Polyamides X-101 and PRD-14

(21) Elastic memory materials, polymeric (polysulfide)

(22) Elastic memory materials, metallic (nitinol)

It is recognized that there is a large additional volume of pertinent information suitable for inclusion in the data sheets. Appendix A will be therefore expanded as that additional information is acquired.

PROPERTIES AND CHARACTERISTICS AFFECTING MATERIALS SELECTION

In establishing criteria for the selection of materials to be used in the low frequency radiotelescope, a primary consideration is the availability of accurate and detailed knowledge of engineering properties upon which successful component designs may be used. Equally important are those characteristics which enable a material to retain its useful properties during the rigorous environments of fabrication, pre-launch checkout, launch, deployment, and service in orbit. A final consideration in such criteria is that technology exists for candidate material which is sufficiently advanced to allow volume procurement of uniformly high quality material so that it may be fabricated into reliable structures.

(1) Special Characteristics in Hard Vacuum: The radiotelescope will operate at an orbital altitude in the range from 2000 km to synchronous altitude. Environmental gas pressures will therefore range from 760 mm Hg at the earth's surface to 10-12 mm Hg and lower at altitudes of 2000 km and beyond (References 11 and 23). One of the effects on the radiotelescope performance will be loss of mass which is accelerated as temperatures increase. The net result can be a serious change in engineering properties. (Reference 20)

Metals and other inorganic materials lose mass through the process of sublimation. The more volatile alloying constituents of metals are lost first, although their loss rates are much lower than the rates for the pure metals. Selective losses of individual grains and grain boundaries produce surface roughness which, for thin films and coatings may alter optical properties needed for thermal control during the five year service life (Reference 20).

Organic materials of interest as radiotelescope structural components are long chain polymeric compounds. However, these degrade with increasing temperature to form volatile breakdown products. Since this process is essentially one of decomposition, rather than sublimation, it occurs not only at surfaces but throughout the entire volume of the component. Diffusion to the surfaces and subsequent volatilizing will proceed more rapidly in thin tapes and tubings than in the thicker sections usually employed for space structures with consequent changes in mass and dimensions. Consideration should be given to the use of barrier coatings to reduce the loss of breakdown products (References 19 and 20).

Another effect of the hard vacuum is the removal of absorbed gases from material surfaces. Unless special precautionary techniques are developed, proper deployment of the reflector network may be arrested by the resulting increased friction between contacting tapes. This effect may be sufficiently great to cause tapes to cold weld together. Again, the development of suitable coatings may provide a solution. Removal of absorbed gas layers may also affect the propagation of cracks originating from micrometeoroid damage. Conflicting results have been reported concerning the inhibition of crack formation in hard vacuum and the mechanics involved must be thoroughly understood for each material considered (Reference 23).

(2) Factors Affecting Micrometeoroid Damage: The flux of micrometeoritic particles near the earth is substantially greater than at altitudes of several earth radii (Reference 1) and is a factor in the altitude range which is considered for radiotelescope operation. For a mission of five years duration, the probability of significant damage due to erosion of thermal control surfaces and fracture of thin structural elements is high.

Velocities of micrometeoroids are extremely high and the kinetic energies involved are considerable despite the fact that particle masses are small. Since space armor or other protection is not feasible for large structures, the effects of collision must be minimized by designing components in appropriate forms. Studies have shown that flat tapes and hollow tubes are far less vulnerable to meteoroid damage than solid circular cross sections. Accordingly, some of the materials for structural elements must be available as tape or tubing, depending on the nature of the loads to be applied (Reference 18).

(3) High Energy Radiation Effects: High energy radiation damage in space occurs primarily through two mechanisms. Ionization, the removal of electrons from the atoms of a material, is the principal cause of damage to plastics and other organic compounds. Depending upon chemical structure, the reaction may be cross-linking with attendant loss in flexibility, or cleavage in which long polymer chains are broken into fragments with subsequent degradation in physical and mechanical properties. Organic films considered for use as network tapes must maintain suitable dimensional form throughout their five year service life.

The second mechanism damages metals through displacement of atoms from their positions in the crystal lattice by collision with impinging particles. Intense irradiation will degrade mechanical, thermal, and electrical properties somewhat but the total effect is too small to be of serious consequence if components are properly designed (References 11 and 23).

(4) Coating and Surface Effects: Atmospheric temperature at orbit altitude is of small consequence since the reduced gas density permits very little energy transfer. The antenna components will, however, be heated by radiation from the sun and earth. Material temperatures may be controlled by adjusting their absorptance to emittance ratios. Depending on the component, this may be accomplished by the application of a suitable coating or, in some cases, by changes in texture of component surfaces. Materials may be required to withstand some thermal stresses and temperature variations since they will, at time, be shaded from solar radiation by other structural elements and the earth. Dimensional changes resulting from thermal expansion and contraction and stresses must not be so great under these conditions, as to affect structural integrity or reflector performance (References 1 and 23).

(5) Corrosion Resistance: With reasonable protection prior to launch, it is unlikely that any material will be structurally affected by corrosion from atmospheric or other sources. However, even minor surface defects caused by handling or atmospheric moisture can seriously affect the absorptance/emittance ratios selected for temperature control. Consequently, surface characteristics must be preservable during fabrication and storage (Reference 11).

(6) Moisture Absorption: Reduced pressures in the space environment will quickly volatilize absorbed moisture. Thus, hygroscopic polymers which depend on absorbed moisture for their ultimate properties must retain an adequate level of performance when dehydrated (Reference 11).

(7) Static Strength: Strength requirements for components are fairly low. Therefore, it should not be a strong factor in the selection of materials for some of the members. In orbit service, values of 100 psi for masts, diagonal members and 10 psi for its longerons may be typical. Stresses imposed during launch are not expected to exceed these levels appreciably. During deployment stress levels of as high as 1000 psi may be employed to straighten out creases in the tapes. Tear strength is a consideration for tapes used in tension as is notched tensile strength for elements of the mast structure since high performance in these respects will minimize damage sustained from meteoroid collision. In summary, high strength materials are not essential.

(8) Fatigue Strength: Three sources of material fatigue must be considered. First is the ascent environment which will impose shock and vibration stresses resulting from engine ignition, engine acoustic pressures, and stage separation shocks. These stresses are expected to be minimal since they will be applied while the antenna is confined in its launch package. The second source originates during deployment when stresses will vary but will be controlled to comparatively low magnitudes and frequencies. The third source occurs during the operational phase when eccentric inertia loads and temperature changes associated with antenna spin will cause low stress level oscillations at low frequencies. To be acceptable, materials (and components) must have an endurance limit strength above the stress levels predicted for the operational phase. They must also be able to withstand applied stresses of the first and second phases without serious loss of endurance limit strength. Oscillating thermal strains and, possibly, thermal stresses must not result in separation of temperature control coatings.

(9) Notch Strength: Many materials may exhibit high strength when unnotched, but because of the long-term exposure of LOFT to meteoroids, its structural elements

(particularly tension tapes) should retain their strength when hit by the smaller (more probable) meteoroids. The ability of a material to do so is indicated by its notch strength or "notch toughness".

(10) Elastic Modulus: The elastic modulus is a primary factor affecting buckling strength of the mast, the dynamic response of the overall structure to oscillating forces, its quasi-static response to centrifugal forces, and the magnitude of thermal stresses. Thus, the materials' elastic moduli, in combination with its density, will greatly influence the weight of the LOFT.

(11) Proportional-Limit Strength: The strength of the mast's longeron material at its proportional limit stress, along with the elastic modulus will limit the packaging radius into which the longerons can be coiled. This proportional-limit strength can therefore significantly affect the material selected for the longerons.

(12) Thermal Properties: The materials' thermal conductivity, specific heat and coefficient of thermal expansion will vitally affect the thermal distortions and thermal stresses of the antenna. These properties accordingly affect mast eccentricities and vibrations resulting from thermal induced eccentricities of masses throughout the antenna. Generally, the materials selected should minimize thermal distortions and stresses.

(13) Structural Damping: The antenna's response to oscillating forces will depend very significantly on the amount of structural damping that is present. Without it structural responses to the continuous spinning with some unavoidable eccentricity of masses, would become unbounded. Frictional disposition of energy that develops between the net elements will provide some of the required damping. However, internal (hysteretic) damping provided by the material itself is desired. Therefore, this capacity could influence the selection of some of the antenna materials.

(14) Electrical Conductivity: Electrical conductivity is a primary design consideration for the reflector network. Similarly, dielectric constant is a basic property in the selection of insulating materials. Both are directly related

to density for radiotelescope application since the bulk of the structure will consist of components which must perform one or the other of these functions. It is important that these properties are adequately defined under all environmental conditions which they will encounter.

(15) Resistance to Creasing: Creasing of thin tapes used in the antenna network may occur both in construction and launch package storage. Tape materials, together with thermal control or other coatings, must either resist creasing or must suffer no significant loss in performance properties as a result of such treatment. For instance, the presence of such creases in tapes will result in an effective reduction in their elastic moduli because the low stresses applied will not completely straighten them.

(16) Density: The density of each material must be considered in relation to other structural and physical properties to determine its influence on structural weight, electrical performance, and long-term dimensional stability.

(17) Variance of Properties: Materials selected must be reliable in the sense that their properties may be accurately predicted within limits which are both known and acceptable. Not only is uniform quality necessary, the techniques of storage, fabrication, and packaging must be defined and controlled to insure preservation of the required performance characteristics.

It is generally desirable that engineering materials have low statistical variance in their essential structural and physical properties. This variance is a primary factor influencing the reliability of structural and functional performance. Without these low variances, conventional factors of safety used in designing with well developed materials, must be replaced with higher ones to achieve equal reliability. Thus, weight penalties are incurred which could reduce the output of data from the experiment. Therefore, this factor must be carefully considered when screening relatively undeveloped materials.

(18) Availability: Materials selected must be available in quantities sufficient to produce the required components. Consequently, a volume manufacturing technology must either exist or must be capable of being developed rapidly enough to permit thorough evaluation of material performance. Experimental materials which cannot be produced in volume, or which are incompletely characterized with respect to quality and performance are necessarily excluded from consideration.

(19) Cost: Material expenses must be considered in terms of cost consequence to the entire system. Antenna performance is of primary inportance and must not be unduly compromised by cost considerations. It is possible that relatively expensive materials will be selected, such as composite tapes and tubings if they effect savings in weight and improvements in reliability that will more than offset their high purchase prices.

(20) Existing Properties Data: In order to produce a properly designed antenna which will function as intended, it is essential that the pertinent engineering properties of each material are known. Incompletely defined experimental materials, no matter how attractive they appear, cannot be considered as candidates.

(21) Existing Technology For Fabrication: Since acceptable materials must be fabricated to produce the required structure, it is necessary that an adequate manufacturing technology exists, or can reasonably be developed within the time limits imposed by the program schedule. Of particular importance to antenna reliability in deployment and service, are such operations as adhesive bonding, vacuum deposition of surface materials, cutting, and forming.

(22) Storability (Shelf Life): Storability requirements will vary among materials, but all must be capable of storage for one year prior to launch. Polymeric materials are especially vulnerable in this respect, as are coatings and surfaces intended for thermal control. Storage requirements for each must be clearly defined and adhered to.

STATUS OF DATA COMPILATION

Following are some of the materials presently under consideration in this program, along with comments as to the status of their investigation:

(1) Aluminum and aluminum coatings were both considered. Aluminum was rated both as a structural material and in the form of foil as an electrical conductor. Vacuum deposited aluminum coatings were considered for thermal control and electrical conductivity.

(2) Mylar* (and metal composites) was not considered at this time due to superior properties of Kapton*. Mylar will be considered at a future date.

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(3) Kapton* (and metal composites) was considered and rated.

(4) Kapton* (and boron composites) was considered and rated.

(5) Stainless steel was rated for use as a structural component.

(6) Steel (and aluminum) composites were discarded due to lack of data on availability and properties.

(7) Silver was not rated at this time, although it merits future consideration in coating form for thermal control and electrical conductivity.

(8) Beryllium was not rated at this time, but merits future consideration for structural applications as components of the mast.

(9) Invar was not rated at this time, but will be considered at a future date for applications which can utilize its stable coefficient of thermal expansion.

(10) Temperature control coatings were not rated as a group at this time. This task should be accomplished as soon as design data which define substrates and coating properties are available.

(11) $A\ell_2O_3$ (on aluminum or other substrates) was not rated at this time due to lack of available data for requirements.

(12) Boron was considered and rated as a constituent of a composite material for structural use.

(13) Silicon carbide (and other ceramics) was not rated at this time since data were not available for composite of appropriate form.

(14) Titanium data has not been compiled as yet, but merits future consideration for use as mast tension components.

(15) Magnesium was rated for use as compression elements of the mast structure. This candidate has good potential for weight savings relative to aluminum; however, it has certain other relatively undesirable properties, such as lack of corrosion resistance and poor fabricability. Data will be completed on magnesium until it is selected or rejected

as a candidate.

(16) Fiber reinforced (metallic, SiO_2) aluminum was discarded since data were not available for composites of appropriate form.

(17) Fibrous glass (aluminum coated) was discarded in favor of fibrous quartz (aluminum coated). Fibrous glass will be considered at a future date.

(18) Fibrous quartz (aluminum coated) was rated for use as reflector tapes.

(19) PBI resins and coatings were discarded since data showing applicability to the radiotelescope were not available at this time.

(20) Polamides X-101 and PRD-14 were discarded since data showing applicability to the radiotelescope were not available at this time.

(21) Elastic memory materials, polymeric (polysulfide) were not rated since requirements for them are not presently defined. They will be considered later for use in protecting network tapes from the effects of creasing.

(22) Elastic memory materials, metallic (nitinol) were not rated since requirements for them are not presently defined. They will be considered later for use in protecting network tapes from the effects of creasing.

References for this section are References nos. 1, 2, 10, 11, 19, 20, 23, 24, 25, 26, 27, and 28.

SELECTION CRITERIA AND RATING INDICES

The foregoing material properties and characteristics are not to be compared individually to select the preferred materials. Instead, these individual materials parameters must be combined into rating indices. Many of the rating indices already exist and are so formulated that they show the effects of combinations of the properties on such overall qualities of the end product as structural efficiency, structural reliability and the effect of the structural material on the overall cost-effectiveness of the LOFT. These various types of rating indices are generally not applied independent of one another. That is, for instance, structual efficiency can usually be gained at the expense of reliability or, by fabricating efficient structures the magnitude of the cost-effectiveness quotient for the total program may be reduced.

Since these concepts of rating indices are not new, their employment in this program to form a rational basis for material selection is a matter of adapting them to the LOFT program's requirements. This adaptation to LOFT requirements will form the materials selection criteria.

To illustrate the applicability of some of these rating indices to the present problem consider first the effect of material selection on the weight of the LOFT mast. Because it will be very lightly loaded, the material's elastic modulus is a key parameter. Reference 30 shows the weight of the column will be proportional to $d/E^{1/2}$ where d is the material's density and E is its elastic modulus. For strength critical components the weight index is d/F_{Ty}, where F_{Ty} is the tensile strength. Regarding cost-effectiveness indices, Reference 31 shows that on that basis the objective is to minimize an index I given by:

$$I = VW_s + C_s$$

where V is a quantity expressing the value, per unit weight, for saving weight on the overall product, W_s is the weight the structural part under consideration and C_s is the total cost of producing the particular structural part. The manner in which the various material properties, costs, and characteristics can influence I, above, is obvious in some instances. The problem in adapting this type of cost minimization to LOFT is one of judiciously evaluating the significance of economy in such a program.

CONCLUSIONS

The interim results of this study indicate that the following materials are preferred candidates:

Aluminized Kapton* film - tape for reflecting net and rim
Kapton Film* - tension tapes
Aluminum alloy tubing - mast longerons and cross members
Aluminum alloy tape - mast diagonals.

It is emphasized, however, that these selections are based on an incomplete compilation of data and no rigorous application of formulated selection criteria. Other materials may well prove to be superior but additional information concerning them must be acquired through continued exploration of the existing literature and, for incompletely characterized materials, by executing specially designed test programs. In some cases, advancements in technology may demonstrate the superiority of materials presently in the terminal stages of development. Composites reinforced with boron filaments and other fibrous materials are representative of this latter group.

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APPENDIX A

MATERIAL DATA SHEETS

(Data Sheet No. 1) Tape & Film, Polyimide, Kapton* Type H

General Information. - Kapton* Type H Film is manufactured by E. I. DuPont De Nemours & Co., (Inc.), Film Department, Industrial Sales Division, 350 Fifth Avenue, New York, N.Y., 10001.

Proposed applications are:

(1) Tensioning tapes

(2) Reflector ribbons (as aluminum/Kapton* composite film)

(3) Mast structure (as tubular elements formed from boron/Kapton* composite film)

Cost and availability are as follows:

Gauge:	Thickness:	Price per lb:	Yield sq. ft per lb:	Approx. ft per roll 6 in. OD:	9½ in. OD:
50	½ mil	$25	272	-	-
100	1 mil	$25	136	1500	5100
200	2 mil	$25	68	750	2550
300	3 mil	$25	45	500	1700
500	5 mil	$25	27	-	1000

Rolls are slit to order in 1/16 inch increments within the limits indicated below. Wider widths up to 36 inches are available for certain items on a special price quotation basis.

Gauge:	Roll OD:	Min. Width:	Max. Width:
All except 500	6 in.	3/16 in.	7/16 in.
All	9½ in.	½ in.	12 in.

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APPENDIX A - MATERIAL DATA SHEETS (CON'T.)
(Data Sheet No. 1) Tape & Film, Polyimide, Kapton* Type H (Con't.)

A related product is designated Kapton* Type F Film which is a polyimide base film coated with Teflon* FEP to impart heat sealability, a moisture barrier, and enhanced chemical resistance (ref. 4).

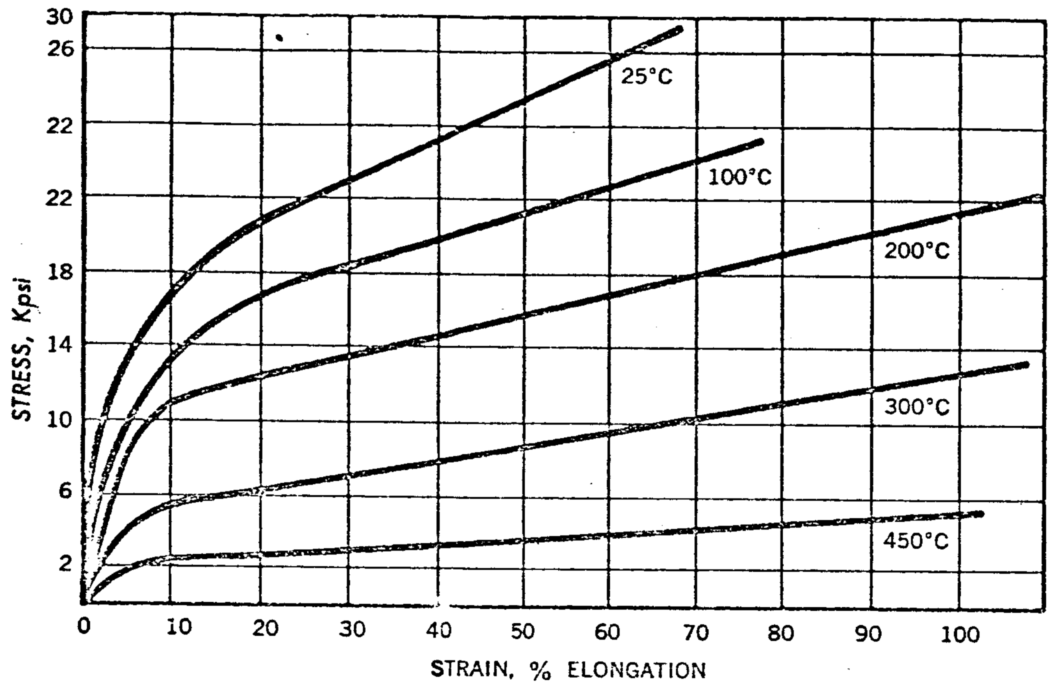
Properties. -

TYPICAL PHYSICAL PROPERTIES
TYPE H FILM 1 MIL (Ref. 5)

PHYSICAL PROPERTIES		TYPICAL VALUES			TEST METHOD
		—195°C	25°C	200°C	
Ultimate Tensile Strength	(MD)	35,000 psi	25,000 psi	17,000 psi	ASTM D-882-64T
Yield Point	(MD)		10,000 psi at 3%	6,000 psi at 3%	ASTM D-882-64T
Stress to Produce 5% Elongation	(MD)		13,000 psi	8,500 psi	ASTM D-882-64T
Ultimate Elongation	(MD)	2%	70%	90%	ASTM D-882-64T
Tensile Modulus	(MD)	510,000 psi	430,000 psi	260,000 psi	ASTM D-882-64T
Impact Strength			6 Kg-cm/mil		Du Pont Pneumatic Impact Test
Folding Endurance (MIT)			10,000 cycles		ASTM D-2176-63T
Tear Strength—Propagating (Elmendorf)			8 gm/mil		ASTM D-1922-61T
Tear Strength—Initial (Graves)			510 gm/mil		ASTM D-1004-61
Bursting Test (Mullen)			75 psi		ASTM D-774-63T
Density			1.42 gm/cc		ASTM D1505-63T
Coefficient of Friction Kinetic (Film-to-Film)			.42		ASTM D-1894-53
Refractive Index (Becke Line)			1.78		Encyclopaedic Dictionary of Physics, Volume I

*DuPont Registered Trademark

APPENDIX A - MATERIAL DATA SHEETS (CON'T.)
(Data Sheet No. 1) Tape & Film, Polyimide, Kapton* Type H (Con't.)



Tensile Stress vs. Strain at Various
Temperatures, Type H Film 1 mil.
(ref. 5).

DIELECTRIC CONSTANT
TYPE H FILM AT 25°C AND 50% R.H.
(ref. 6)

Dielectric Constant 1 mil 2 mil 3 mil 5 mil	3.5 3.6 3.7 3.7	1 kilocycle	ASTM D-150-59T

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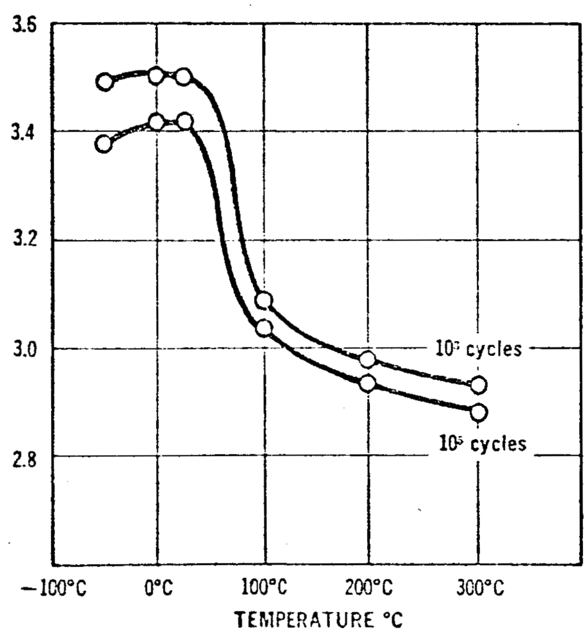
RELATIVE HUMIDITY VS. DIELECTRIC CONSTANT
TYPE H FILM 1 MIL @ 25°C (ref 6)

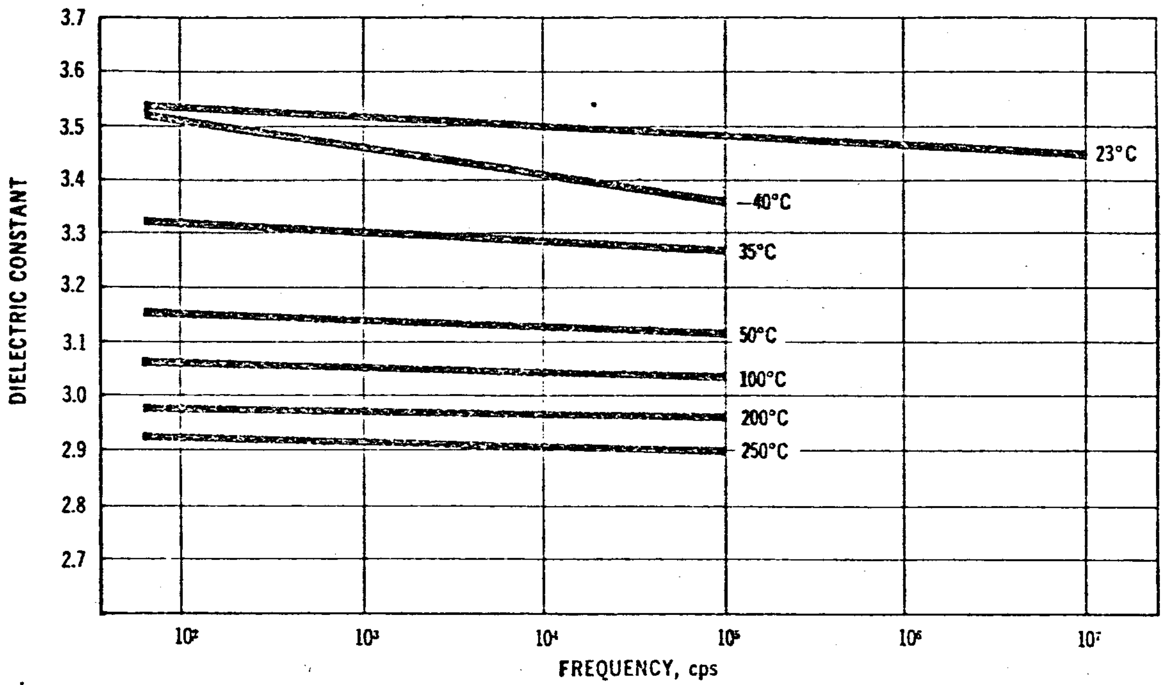
% Relative Humidity:	Dielectric Constant:	Absolute Water Content, %:
0	3.0	-
30	3.3	-
50	3.5	1.3
80	3.7	-
100	3.9	2.9



Dielectric Constant vs. Temperature
Type H Film 1 mil (ref. 6)

* DuPont Registered Trademark

APPENDIX A - MATERIAL DATA SHEETS (CON'T.)
(Data Sheet No. 1) Tape & Film, Polyimide, Kapton* Type H (Con't.)



Dielectric Constant vs. Frequency
Type H Film 1 mil (ref. 6).

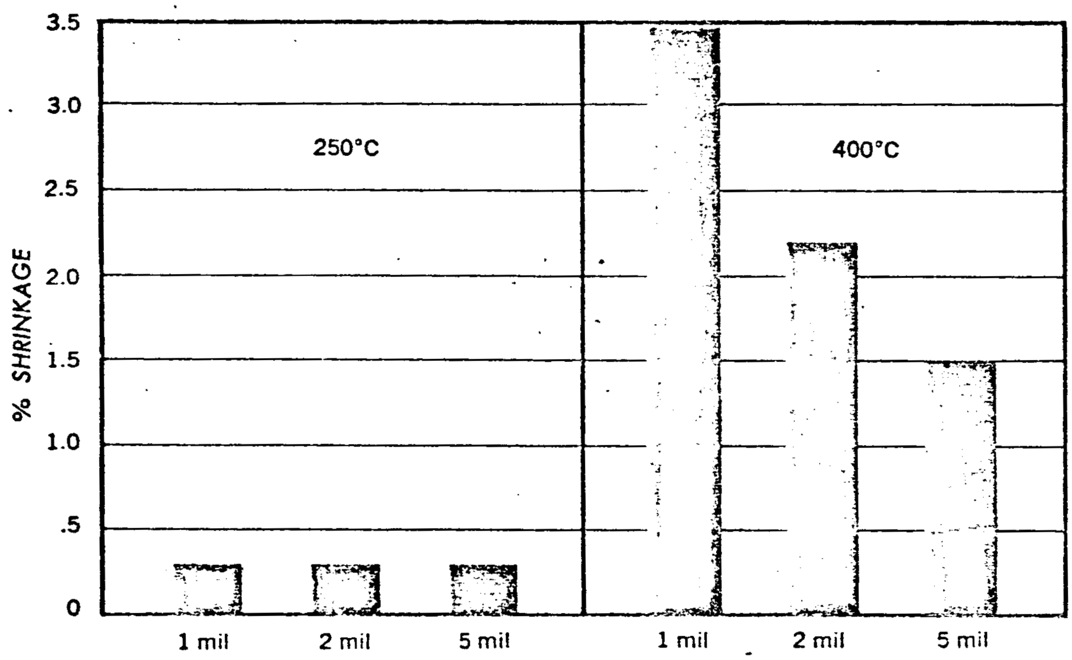
TYPICAL THERMAL PROPERTIES
TYPE H FILM - 1 MIL (ref. 5)

THERMAL PROPERTIES	TYPICAL VALUES	TEST CONDITION	TEST METHOD
Melting Point	NONE		
Zero Strength Temperature	815°C	20 psi load for 5 seconds	Hot Bar (Du Pont Test)
Coefficient of Linear Expansion	2.0×10^{-5} in./in./°C	(—) 14°C to 38°C	ASTM D-696-44
Coefficient of Thermal Conductivity	3.72×10^{-4} $\frac{(cal)\,(cm)}{(cm^2)\,(sec)\,(°C)}$	25°C	Model TC-1000
	3.89×10^{-4} "	75°C	Twin Heatmaster
	4.26×10^{-4} "	200°C	Comparative Tester
	4.51×10^{-4} "	300°C	
Specific Heat	.261	cals/gm/°C	Differential Calorimetry
Flammability	Self-extinguishing		
Heat Sealable	No		

* Dupont Registered Trademark

(Data Sheet No. 1) Tape & Film, Polyimide, Kapton* Type H (Con't.)

Residual manufacturing stresses (ref. 5) cause shrinkage in Type H Film on its initial exposure to elevated temperatures. The bar graph below indicates the magnitude of this initial shrinkage at two temperatures.



Initial Shrinkage vs. Exposure Temperature and Gauge, Type H Film (ref. 5).

Temperature Range	"K" in/in °C. x 10^5
23-100°C.	1.80
100-200°C.	3.10
200-300°C.	4.85
300-400°C.	7.75
23-400°C.	4.55

Thermal Coefficient of Expansion Type H Film 1 mil (Previously Thermally Exposed) (ref. 5).

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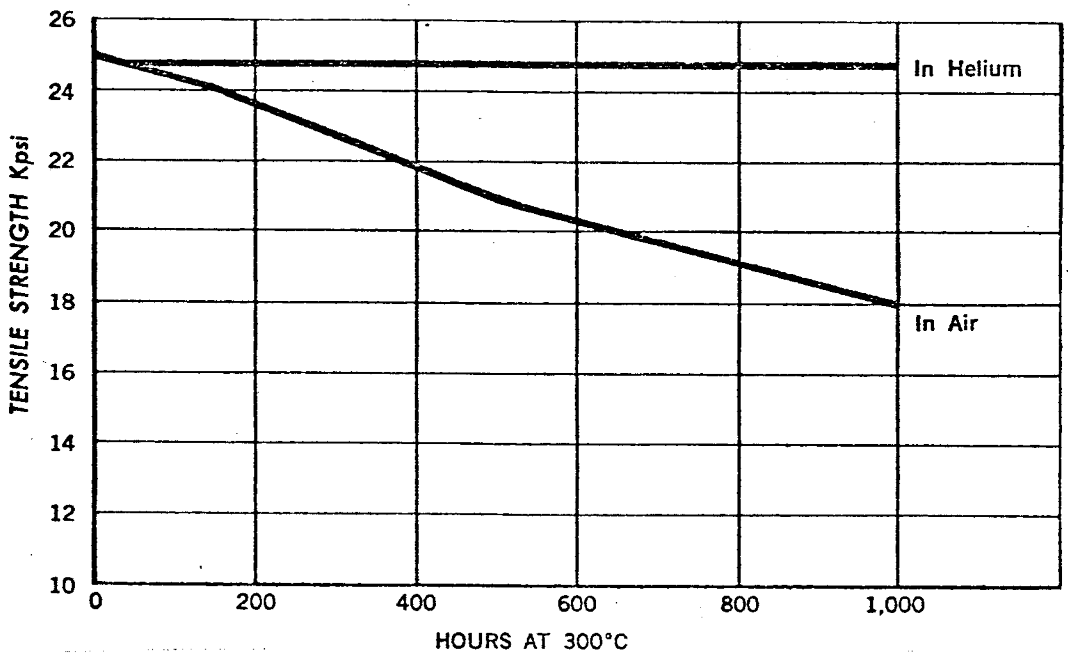
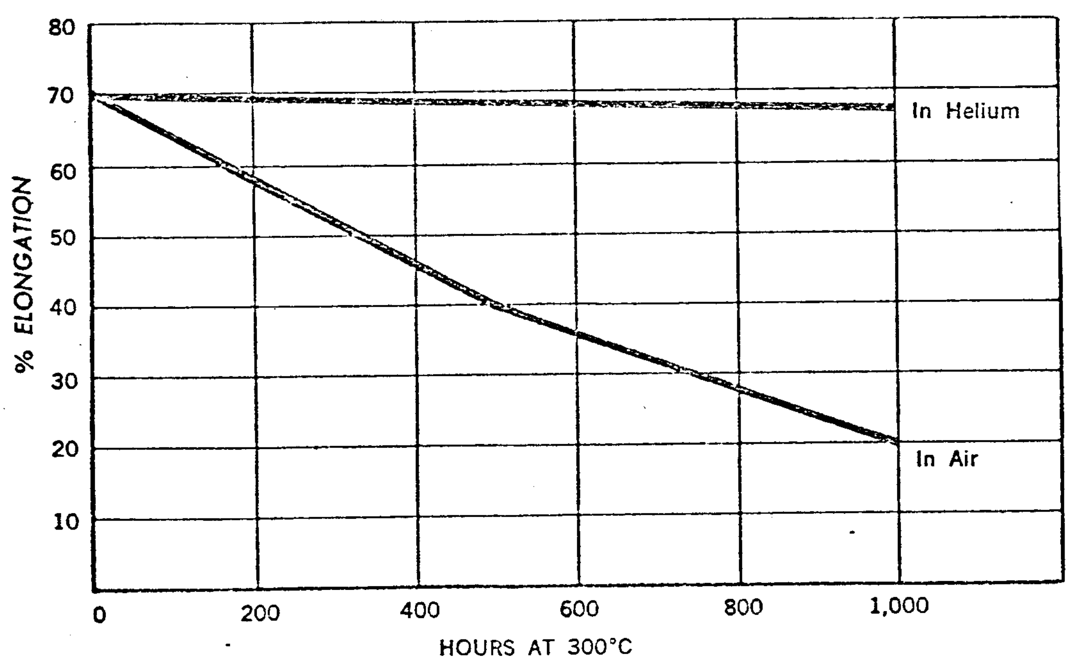
APPENDIX A - MATERIAL DATA SHEETS (CON'T.)
(Data Sheet No. 1) Tape & Film, Polyimide, Kapton* Type H (Con't.)



Tensile Strength vs. Aging at 300°C
Type H Film 1 Mil (ref. 5).



Ultimate Elongation vs. Aging at 300°C
Type H Film 1 Mil (ref. 5).

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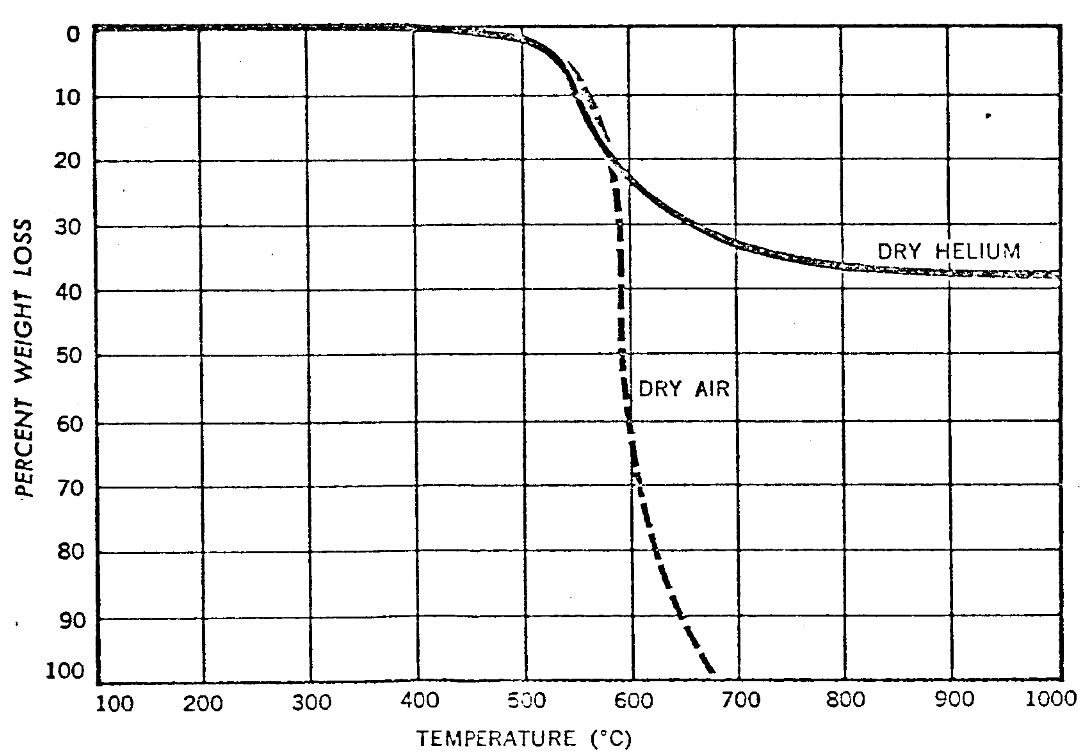
(Data Sheet No. 1) Tape & Film, Polyimide, Kapton* Type H (Con't.)

TIME REQUIRED FOR REDUCTION IN ULTIMATE
ELONGATION FROM 70% TO 1%
TYPE H FILM 1 MIL (ref. 5)

Temperature	Environment	
	Air	Helium
450°C.	2 hours	22 hours
425°C.	5 hours	3½ days
400°C.	12 hours	2 weeks
375°C.	2 days	2 months
350°C.	6 days	1 year
300°C.	3 months	—
275°C.	1 year	—
250°C.	8 years	—



Weight Loss at 3°C/Minute Temperature Rise
Type H Film 1 Mil (ref. 5).

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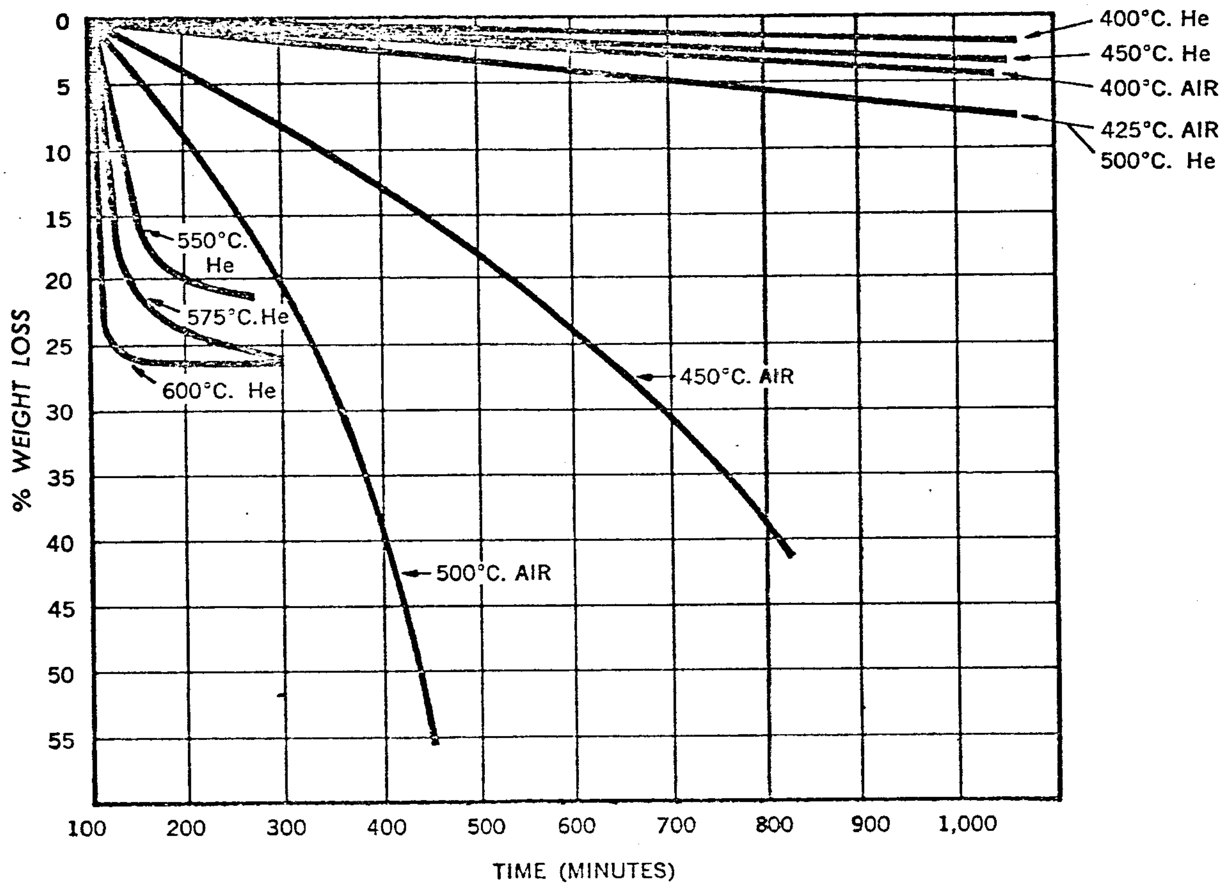

Isothermal Weight Loss
Type H Film 1 Mil (ref. 5)

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CRYOGENIC TENSILE PROPERTIES OF TYPE H FILM (ref. 5)

Tensile Strength (KPSI)	25°C	-195°C	-269°C
A 3-mil		43	
B 5-mil MD/TD	22/18	35/27	
C 5-mil		34	33
D 1-mil	30	45	
E 1-mil	25	35	

Elongation (%)	25°C	-195°C	-269°C
A 3-mil		6	
B 5-mil	74/79	12/8	
C 5-mil		6	5
D 1-mil	140	24	
E 1-mil	70	2	

Modulus (KPSI)	25°C	-195°C	-269°C
A 3-mil		1000	
B 5-mil	200/200	420/500	
C 5-mil		890	800
E 1-mil	430	510	

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Environmental Characteristics. -

EFFECT OF ULTRAVIOLET EXPOSURE ON TYPE H FILM (ref. 5)

(Lewis Research Center)

	Control:	1000 hrs Vacuum UV:
Tensile Strength (KPSI)	21	21
Elongation (%)	106	78

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APPENDIX A - MATERIAL DATA SHEETS (CON'T.)
(Data Sheet No. 1) Tape & Film, Polyimide, Kapton* Type H (Con't.)

EFFECT OF GAMMA EXPOSURE ON TYPE H FILM (ref. 5)

CO^{60} Source (Oak Ridge)

Property:	Control: (1-mil film)	10^6R: 1 hr	10^7R: 10 hrs	10^8R: 4 days	10^9R: 42 days	1.5×10^{10}R: 625 days
Tensile Strength (KPSI)	30	30	31	31	22	<10% of initial tensile and elongation
Elongation (%)	80	78	78	79	42	-
Tensile Modulus (KPSI)	460	475	490	475	421	-
Dielectric Constant (1KC)	3.46	3.54	3.63	3.71	3.50	-

CO^{60} Source (Langley Research Center)

	Control:	2×10^9R: Air	2×10^9R: Vacuum
Tensile Strength (KPSI)	21.7	17.2	24.4
Elongation (%)	87	36	84

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APPENDIX A - MATERIAL DATA SHEETS (CON'T.)
(Data Sheet No. 1) Tape & Film, Polyimide, Kapton* Type H (Con't.)

EFFECT OF ELECTRON EXPOSURE ON TYPE H FILM (ref. 5.)
2 MEV ELECTRONS (Van De Graaf)

Property:	Control: (2-mil film)	1×10^9R:	2×10^9R:	3×10^9R:	6×10^9R:
% of Initial Tensile and Elongation Retained	100%	89%	78%	75%	50%
Dielectric Constant (1KC)	3.5	3.4	3.9	4.2	-

EFFECT OF NEUTRON EXPOSURE ON TYPE H FILM (ref. 5)

Mixed Neutron and Gamma Radiation (Brookhaven Pile)

	5×10^9R:	10^{10}R:
Temperature 175°C Flux 5×10^{12} n/cm^2/sec	Film Darkened	Film Darkened and Tough

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APPENDIX A - MATERIAL DATA SHEETS (CON'T.)

(Data Sheet No. 2) Foil, Aluminum

General Information. - Aluminum foil as available from Kaiser Aluminum and Metals Corporation, Reynolds Metals Company, and others can be considered for use as reflector ribbons in the antenna network. The foil may be used unsupported or may be laminated with adhesive to a suitable substrate such as Kapton* or Mylar*. Foil material is usually pure aluminum or alloy 1080, 1145, or 3003.

Current cost of alloy 1145, soft, slit into ribbon 0.0005 inches thick by 1/8 inch wide, is $5.879 per pound in quantities of 10 pounds from Republic Foil Inc., Danbury, Conn.

Properties. - The chemical compositions of some aluminum foil materials are tabulated below (ref. 16).

	Mn (percent)	Al (percent)
Pure Aluminum	-	99.996
Alloy 1145 (Republic)	-	99.45
Alloy 3003	1.2	Remainder

Typical physical properties for pure aluminum and for alloy 3003 are tabulated below. Data are from sheet specimens and may not describe foil exactly (ref. 15, 16).

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APPENDIX A - MATERIAL DATA SHEETS (CON'T.)

(Data Sheet No. 2) Foil, Aluminum (Con't.)

	Pure Aluminum	Alloy 3003-0
Density, g/cm^3 @20°C.	2.6989	2.73
Specific Weight, $lb/in.^3$ @68°F.	0.09751	0.099
Melting Point, °F.	1220.4	1200
Electrical Conductivity at 20°C., % IACS	64.94	46
Thermal Conductivity at 25°C., $cal/cm/cm^2/°C./sec$	-	0.42

Typical mechanical properties for pure aluminum and for alloy 3003 are tabulated below. Data are from sheet and may not describe foil exactly (ref. 15, 16).

	Annealed Pure Aluminum	Alloy 3003-0
Modulus of Elasticity, psi	9×10^6	10×10^6
Poisson's Ratio	-	0.33
Modulus of Rigidity, psi	-	3.75×10^6
Tensile Strength, psi	6800	16,000
Yield Strength, psi	1700	6,000
Elongation, Percent	60	30
Hardness, Brinell, 500 kg Load, 10 mm Ball	17	28
Shear Strength, psi	-	11,000
Fatigue Limit, 500×10^6 cycles, R-R, Moore Machine	-	7,000

Values for thermal expansion in the range -200°C. to +500°C. are tabulated below for pure aluminum and for alloy 3003 (ref. 16).

Temperature, °C.	Micro-in./in/°C. Pure Aluminum	Alloy 3003
-200 to 20	18.0	-
-150 to 20	19.9	-
-100 to 20	21.0	-
- 50 to 20	21.8	21.4
20 to 100	23.6	23.2
20 to 200	24.5	24.3
20 to 300	25.5	25.0
20 to 400	26.4	-
20 to 500	27.4	-

Environmental Characteristics. - The ratio of solar absorptance to emmittance (α_s/ϵ) is 3.0, + 0.05, - 0.04 for MIL-A-148 aluminum foil. Absorptance and emmittance at 70°F. are:

$$\alpha_s = 0.12 \pm 0.04$$

$$\epsilon = 0.05 \pm 0.02 \quad \text{(ref. 2)}$$

Metals used in the high vacuum of space are subject to loss of their volatile alloying constituents. Tabulated below are the nominal constituents of pure aluminum and alloy 3003 together with temperatures for selected sublimation rates. It should be noted that even at temperatures elevated sufficiently to permit creep under load, the maximum loss rate from the alloy will be less than from the pure volatile metal in proportion to the composition of the metal (ref. 11).

Element:	Sublimation Temperature Rate: 10^{-5} cm/yr (1000 A/yr) °C.	°F.	10^{-3} cm/yr (0.0004 in/yr) °C.	°F.	10^{-1} cm/yr (0.040 in/yr) °C.	°F.	Melting Point:	
Mn	450	840	540	1010	650	1200	1240	2270
Al	550	1020	680	1260	810	1490	660	1220

Metals present no radiation damage problems except at extremely high doses of the order of $1 \times 10^{19} n/cm^2$ or greater such as those which might be obtained from reactor fluxes (ref. 1). Typical effects of neutron irradiation on mechanical properties are shown below for pure annealed aluminum. Values shown are for an exposure of 800×10^{18} n/cm^2 (ref. 17).

	Control:	Irradiated:
Tensile Strength, psi	6,600	12,200
Yield Strength, psi	2,100	5,500
Elongation, percent	46	30

(Data Sheet No. 3) Tubing, Aluminum Alloy 2024-T3

General Information. - Aluminum tubing as supplied by Aluminum Company of America and others is available in a wide range of alloys which vary widely in their respective performance characteristics. For proposed use as longerons and other structural elements of the mast, alloy 2024-T3 is a logical candidate since it possesses good physical and mechanical properties and lends itself well to conventional fabrication techniques.

Cost data given here are for alloy 2024-T3 tubing, 1/2 inch O.D. with a wall thickness of 0.020 inches. The data are current estimates subject to mill acceptance and are based on standard mill lengths of 10 to 12 feet. For a quantity of 200 feet (for model construction) the cost is $0.13 per foot with a set-up change of $130. For a quantity of 30,000 feet (for full scale mast construction) the cost is $0.134 per foot without set-up charge (ref. 14).

Properties. - The following data are for drawn tubing, alloy 2024-T3, and represent minimum values for specimens tested parallel to the direction of drawing (ref. 15).

Wall Thickness (inches)	Tensile Strength (Psi, minimum)		Elongation (per cent, minimum)	
	Ultimate	Yield	Full Section	Cut-out
0.018 - 0.024	64,000	42,000	10	-
0.025 - 0.049	64,000	42,000	12	10
0.050 - 0.259	64,000	42,000	14	10
0.260 - 0.500	64,000	42,000	16	12

Elongation values are for 2 inch gauge lengths on full section specimens or gauge lengths equal to 4 times the diameter of a cut-out specimen. Round tubes 2 inches or less in outside diameter and square tubes 1-1/2 inches or less on a side are tested in full section unless limitations of the testing machine preclude the use of such a specimen. For tubings larger than these sizes, or for tubings of other shapes, or in other cases where a full section cannot be used, a cut-out specimen is tested.

The chemical composition of alloy 2024 is tabulated below (ref. 15).

(Data Sheet No. 3) Tubing, Aluminum Alloy 2024-T3 (Con't.)

Constitutent	Nominal Composition (per cent)	Composition Limits (per cent)
Silicon	-	0.50 max.
Iron	-	0.50 max.
Copper	4.5	3.8 - 4.9
Manganese	0.6	0.30 - 0.9
Magnesium	1.5	1.2 - 1.8
Chromium	-	0.10 max.
Zinc	-	0.25 max.
Total other	-	0.15 max.
Aluminum	Remainder	Remainder

Typical physical properties of alloy 2024-T3 are tabulated below (ref. 14):

Specific gravity, g/cm^3	2.77
Specific weight, $lbs/in.^3$	0.100
Melting Range, approx. °F	935-1180
Electrical conductivity at 20°C (68°F), per cent of International Annealed Copper Standard.	30
Thermal Conductivity at 25°C (77°F), $cal/cm/cm^2/°c/sec$	0.29

Typical mechanical properties of alloy 2024-T3 are tabulated below. The data are average for the various forms available and may not describe tubing exactly (ref. 15).

Ultimate tensile strength, psi	70,000
Yield strength, psi	50,000
Elongation in 2 inches (1/16" thick), per cent	18
Hardness, Brinell, 500 kg load, 10 mm ball	120
Shearing strength, psi	41,000
Fatigue endurance limit, psi	20,000 (A)
Modulus of Elasticity, psi	10.6×10^6 (B)

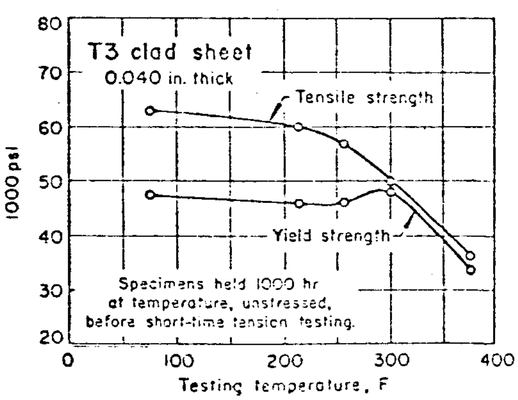
(A) Based on 500,000,000 cycles of completely reversed stress using the R. R. Moore type of machine and specimen.

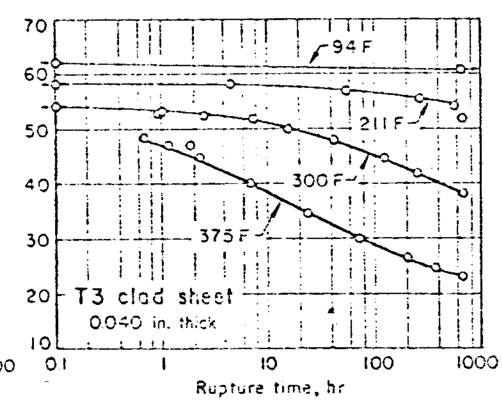
(B) Average of tension and compression moduli. Compression modulus is about 2 per cent greater than tension modulus.

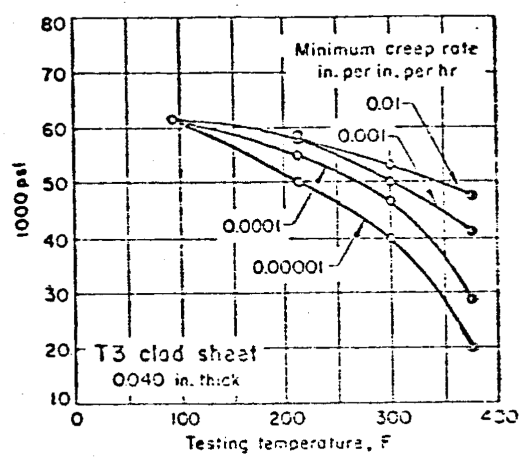
Typical tensile properties of alloy 2024-T3 at various temperatures are tabulated below. Reported data are the lowest strengths during 10,000 hours of heating at testing temperature under no load; stress applied at 5,000 psi/minute to yield strength and then at strain rate of 0.05 in./in./min. to failure. For measurement of elongation, offset equals 0.2 per cent (ref. 15).

Temperature (°F)	Tensile Strength (psi) Ultimate	Tensile Strength (psi) Yield	Elongation in 2 inches (per cent)
-320	85,000	62,000	18
-112	75,000	52,000	17
-18	72,000	51,000	17
75	70,000	50,000	17
212	66,000	48,000	16
300	55,000	50,000	11
400	29,000	22,000	23
500	12,000	9,000	55
600	8,000	6,000	75
700	5,500	4,000	100

Additional data for tensile properties of alloy 2024-T3 at various temperatures are presented in the following graphs (ref. 16).







Values for thermal expansion over the range -76°F to +572°F are tabulated below for alloy 2024 (ref. 16).

Range, °F	Range, °C	Micro-in./in/°C
-76 to +68	-60 to +20	21.4
68 to 212	20 to 100	22.8
68 to 392	20 to 200	23.9
68 to 572	20 to 300	24.7

Fabrication ratings for alloy 2024-T3 are listed below (ref. 15).

Resistance to corrosion	Fair
Workability, cold	Fair
Machinability	Good
Brazeability	No commonly used method so far developed.
Weldability:	
Gas	No commonly used method so far developed.
Arc	Special techniques
Resistance, spot and seam	Special techniques

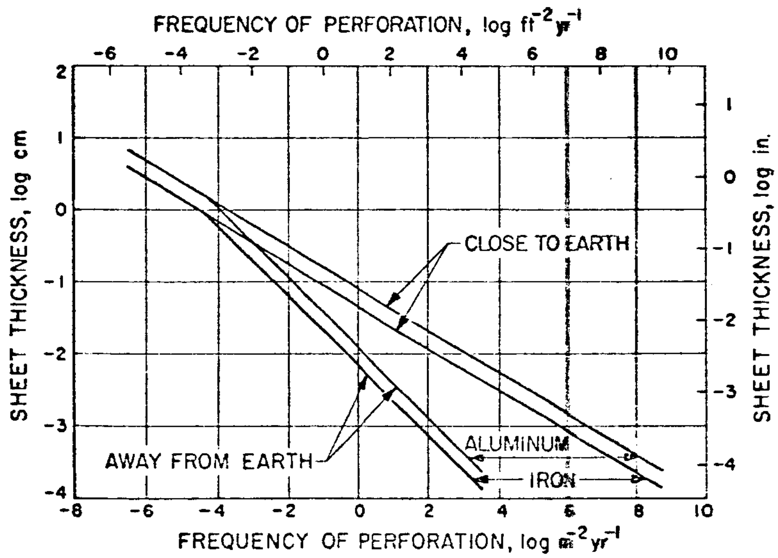
Environmental Characteristics. Alloys used in the high vacuum of space are subject to loss of their volatile alloying constituents. Tabulated below are the nominal constituents of alloy 2024 together with temperatures for selected sublimation rates. It should be noted that even at temperatures elevated sufficiently to permit creep under load, the maximum loss rate from the alloy will be less than from the pure volatile metal

APPENDIX A - MATERIAL DATA SHEETS (CON'T.)
(Data Sheet No. 3) Tubing, Aluminum Alloy 2024-T3 (con't.)

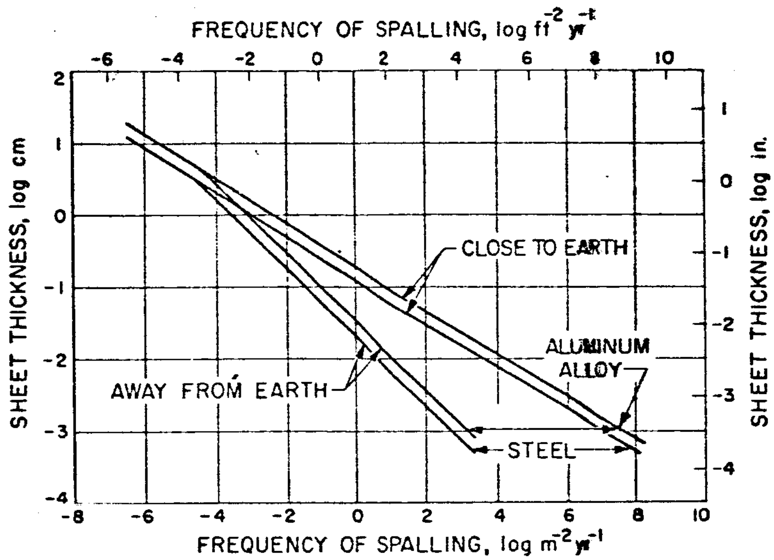
in proportion to the composition of the alloy (ref. 11).

Element:	Sublimation temperature rate: 10^{-5} cm/yr (1000 A/yr) °C	°F	10^{-3} cm/yr (0.0004 in/yr) °C	°F	10^{-1} cm/yr (0.040 in/yr) °C	°F	Melting Point: °C	°F
Cu	630	1160	760	1400	900	1650	1080	1980
Mn	450	840	540	1010	650	1200	1240	2270
Mg	110	230	170	340	240	470	650	1200
Aℓ	550	1020	680	1260	810	1490	660	1220

Erosion by meteoroids is significant only close to earth. Much more frequent than penetration is spalling of fragments from the insides of walls struck by meteoroids. The following two diagrams illustrate the frequencies of these effects in the vicinity of the earth's orbit (ref. 11).



(Data Sheet No. 3) Tubing, Aluminum Alloy 2024-T3 (con't.)



Metals present no radiation damage problems except at extremely high doses of the order of 1 x 10^{19} n/cm^2 or greater such as those which might be obtained from reactor fluxes (ref. 1). Typical effects of neutron irradiation on mechanical properties are shown below for alloy 2024. Values shown are for a temperature of 120°F and an exposure of 984 x 10^{18} n/cm^2 (ref. 17).

	Control	Irradiated
Tensile strength, psi	71,600	84,900
Yield strength, psi	45,300	66,200
Elongation, per cent	26	24

(Data Sheet No. 4) Tubing, Aluminum Alloy 7075-T6

General Information. - Aluminum alloy tubing as supplied by Aluminum Company of America and others is available in a wide range of alloys which vary considerably in their respective performance characteristics. For proposed use as longerons and other structural elements of the mast, stiffness is of primary interest and alloy 7075-T6 with its relatively high modulus of elasticity is a logical candidate. Other factors such as means of fabrication must be considered, however, and a requirement for welding or brazing will probably dictate the selection of another alloy.

Cost data given here are for alloy 7075-T6 tubing, 1/2 inch O.D. with a wall thickness of 0.020 inches. The data are current estimates subject to mill acceptance and are based on standard mill lengths of 10 to 12 feet. For a quantity of 200 feet (for model construction) the cost is \$0.1581 per foot plus a set-up charge of \$130. For a quantity of 30,000 feet (for full scale mast construction) the cost is \$0.169 per foot without set-up charge (ref. 14).

Properties. - The following data are for extruded tubing, alloy 7075-T6, and represent minimum values for specimens tested parallel to the direction of extrusion (ref. 15).

Wall Thickness (inches)	Tensile Strength (psi, minimum) Ultimate	Yield	Elongation (per cent, minimum)
Up thru 0.249	78,000	70,000	7
0.250 - 0.499	81,000	73,000	7
0.500 - 2.999	81,000	72,000	7

Elongation values are for 2 inch gauge lengths on full section specimens or gauge lengths equal to 4 times the diameter of a cut-out specimen. Round tubes 2 inches or less in outside diameter and square tubes 1-1/2 inches or less on a side are tested in full section unless limitations of the testing machine preclude the use of such a specimen. For tubing, larger than these sizes, or for tubings of other shapes, or in other cases where a full section cannot be used, a cut-out specimen is tested.

The chemical composition of alloy 7075 is tabulated below (ref. 15).

(Data Sheet No. 4) Tubing, Aluminum Alloy 7075-T6 (con't.)

Constituent	Nominal Composition (per cent)	Composition Limits (per cent)
Silicon	-	0.50 max.
Iron	-	0.7 max
Copper	1.6	1.2 - 2.0
Manganese	-	0.30 max.
Magnesium	2.5	2.1 - 2.9
Chromium	0.30	0.18 - 0.40
Zinc	5.6	5.1 - 6.1
Titanium	-	0.20 max.
Total other	-	0.15 max.
Aluminum	Remainder	Remainder

Typical physical properties of alloy 7075-T6 are tabulated below (ref. 15).

Specific gravity, g/cm^3	2.80
Specific weight, $lbs/in.^3$	0.101
Melting range, approx. °F	890-1175
Electrical conductivity at 20°C (68°F), per cent of International Annealed Copper Standard.	33
Thermal conductivity at 25°C (77°F), $cal/cm/cm^2/°C/sec$	0.31

Typical mechanical properties of alloy 7075-T6 are tabulated below. The data are average for the various forms available and may not describe tubing exactly (ref. 15).

Ultimate tensile strength, psi	83,000 (A)
Yield strength, psi	73,000 (A)
Elongation in 2 inches, per cent	11
Hardness, Brinell, 500 kg load, 10mm ball	150
Shearing strength, psi	48,000
Fatigue endurance limit, psi	22,000 (B)
Modulus of elasticity, psi	10.4×10^6 (C)

(A) Extruded products have strengths approximately 10 per cent higher than the values shown.

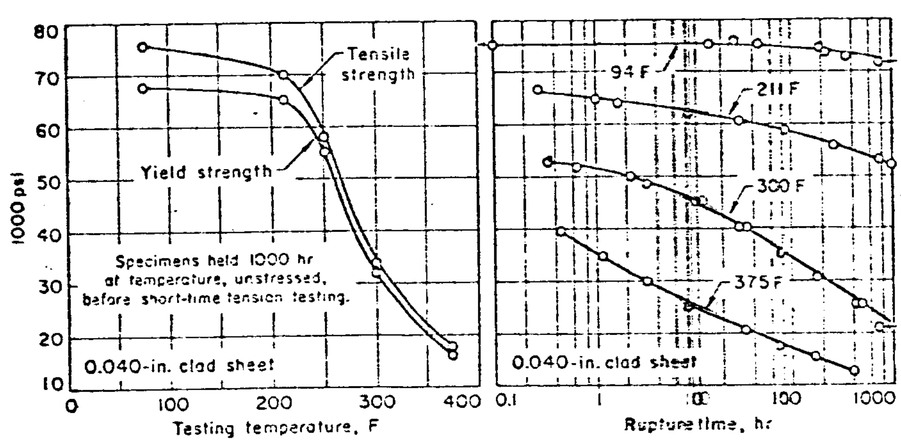
(B) Based on 500,000,000 cycles of completely reversed stress using the R. R. Moore type of machine and specimen.

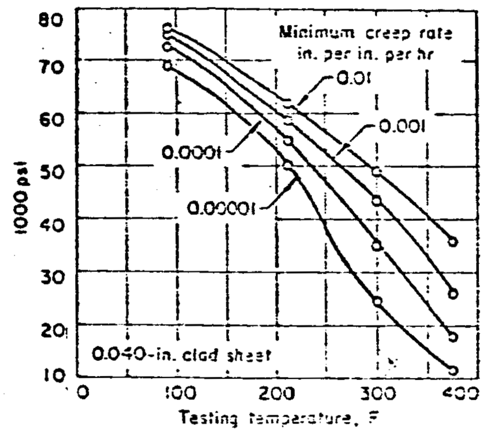
(C) Average of tension and compression moduli. Compression modulus is about 2 per cent greater than tension modulus.

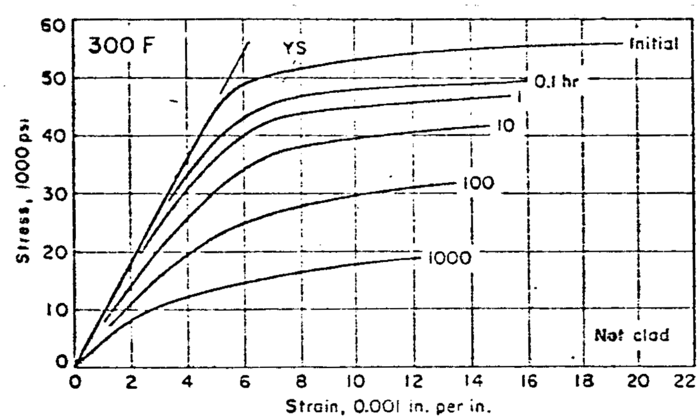
Typical tensile properties of alloy 7075-T6 at various temperatures are tabulated below. Reported data are the lowest strengths during 10,000 hours of heating at testing temperature under no load; stress applied at 5,000 psi/minute to yield strength and then at strain rate of 0.05 in./in./min. to failure. For measurement of elongation, offset equals 0.2 per cent (ref. 15).

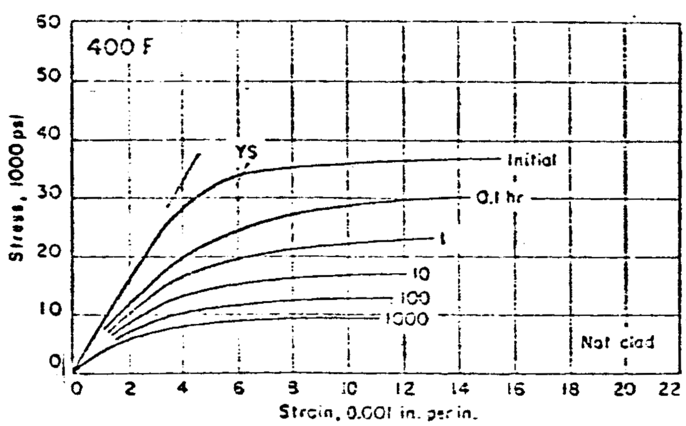
Temperature (°F)	Tensile Strength (psi) Ultimate	Yield	Elongation in 2 inches (per cent)
-320	102,000	92,000	9
-112	90,000	79,000	11
-18	86,000	75,000	11
75	83,000	73,000	11
212	70,000	65,000	14
300	31,000	27,000	30
400	16,000	13,000	55
500	11,000	9,000	65
600	8,000	6,500	70
700	6,000	4,500	70

Additional data for tensile properties of alloy 7075-T6 at various temperatures are presented in the following graphs (ref. 16).




Minimum creep rate
in. per in. per hr
0.01
0.001
0.0001
0.00001
0.040-in. clad sheet
1000 psi
Testing temperature, F


300 F
YS
Initial
0.1 hr
1
10
100
1000
Not clad
Stress, 1000 psi
Strain, 0.001 in. per in.


400 F
YS
Initial
0.1 hr
1
10
100
1000
Not clad
Stress, 1000 psi
Strain, 0.001 in. per in.

(Data Sheet No. 4) Tubing, Aluminum Alloy 7075-T6 (con't.)

Values for thermal expansion over the range -76°F to +572°F are tabulated below for alloy 7075 (ref. 16).

Range, °F	Range, °C	Micro-in./in./°C
-76 to +68	-60 to +20	21.8
68 to 212	20 to 100	23.2
68 to 392	20 to 200	24.3
68 to 572	20 to 300	25.9

Fabrication ratings for alloy 7075-T6 are listed below (ref. 15).

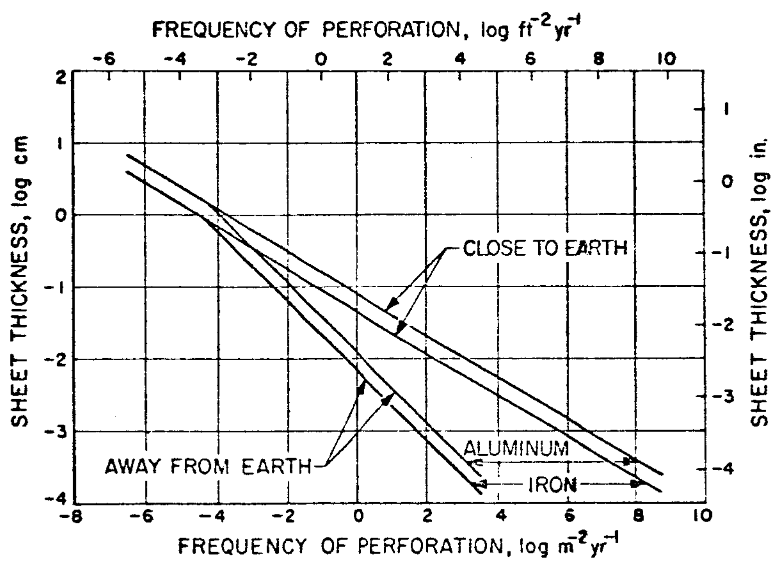
Resistance to corrosion	Fair
Workability, cold	Poor
Machinability	Good
Brazeability	No commonly used method so far developed.
Weldability:	
Gas	No commonly used method so far developed.
Arc	No commonly used method so far developed.
Resistance, spot and seam	Special techniques

Environmental Characteristics. Alloys used in the high vacuum of space are subject to loss of their volatile alloying constituents. Tabulated below are the nominal constituents of alloy 7075 and temperatures for selected sublimation rates. It should be noted that even at temperatures elevated sufficiently to permit creep under load, the maximum loss rate from the alloy will be less than from the pure volatile metal in proportion to the composition of the alloy. For example, the loss rate of zinc in alloy 7075 will not exceed about 2 per cent of the rate for pure zinc (ref. 11).

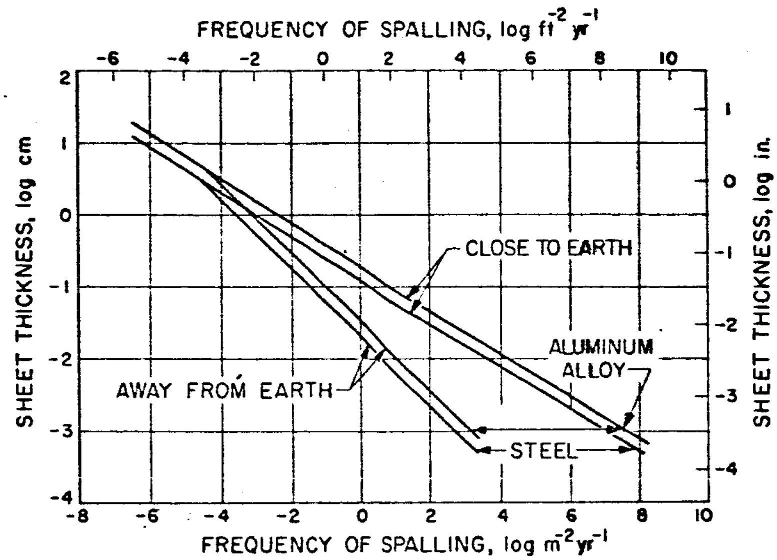
(Data Sheet No. 4) Tubing, Aluminum Alloy 7075-T6 (con't.)

Element:	Sublimation Temperature rate: 10^{-5} cm/yr (1000 Å/yr) °C	°F	10^{-3} cm/yr (0.0004 in/yr) °C	°F	10^{-1} cm/yr (0.040 in/yr) °C	°F	Melting Point: °C	°F
Cu	630	1160	760	1400	900	1650	1080	1980
Mg	110	230	170	340	240	470	650	1200
Cr	750	1380	870	1600	1000	1840	1880	3410
Zn	70	160	130	260	180	350	420	790
Aℓ	550	1020	680	1260	810	1490	660	1220

Erosion by meteoroids is significant only close to earth. Much more frequent than penetration is spalling of fragments from the insides of walls struck by meteoroids. The following two diagrams illustrate the frequencies of these effects in the vicinity of the earth's orbit (ref. 11).



(Data Sheet No. 4) Tubing, Aluminum Alloy 7075-T6 (con't.)



Metals present no radiation damage problems except at extremely high doses of the order of 1 x 10^{19}n/cm^2 or greater such as those which might be obtained from reactor fluxes (ref. 1). Typical effects of neutron irradiation on mechanical properties are shown below for alloy 2024. Data for alloy 7075 are not available. Values shown are for a temperature of 120°F and an exposure of 984 x 10^{18}n/cm^2 (ref. 17).

	Control	Irradiated
Tensile strength, psi	71,600	84,900
Yield strength, psi	45,300	66,200
Elongation, per cent	26	24

(Data Sheet No. 5) Stainless Steel, Alloy 304

General Information. - Stainless steel has been widely used in space applications where strength and temperature requirements are high. This material is considered for use as diagonal members for the lattice compression column (mast) in two forms:

(1) As rolled tape

(2) In fibrous form in composite with other materials.

Properties. - Nominal physical and mechanical properties for type 304 stainless steel are tabulated below (ref. 16).

Tensile Strength, annealed, psi	85,000
Yield Strength, 0.2%, annealed, psi	35,000
Elongation in 2 in., annealed, percent	55
Reduction of area, annealed, percent	65
Hardness, Rockwell	B80
Hardness, Brinell	150
Modulus of elasticity in tension, psi	28×10^6
Modulus of elasticity in torsion, psi	12.5×10^6
Density, g/cm^3	7.9
Specific Weight, $lb/in.^3$	0.29
Specific Electrical Resistance at R.T., microhm-cm	72
Thermal Conductivity, $Btu/hr/ft^2/ft/°F.$,	
212°F.	9.4
392°F.	10.3
572°F.	11.0
752°F.	11.8
932°F.	12.5

Mean coefficient of thermal expansion, per °F.,

32°F. to 212°F.	9.6×10^{-6}
32°F. to 572°F.	9.9×10^{-6}
32°F. to 932°F.	10.2×10^{-6}
32°F. to 1112°F.	10.4×10^{-6}
32°F. to 1832°F.	11.2×10^{-6}
Melting range, °F.	2550 to 2650

APPENDIX A - MATERIAL DATA SHEETS (CON'T.)

(Data Sheet No. 5) Stainless Steel, Alloy 304 (Con't.)

Stainless steel filaments and yarns of 90 to 300 filaments manufactured by Brunswick Corporation are identified as Brunsmet MF-Al. Approximate analysis is 304 type austenitic stainless steel. Filament diameters range from 4 to 50 microns. Typical mechanical properties for single filaments are tabulated below (ref. 29).

	Annealed	Hard
Filament diameter, nominal, microns	12	12
Coefficient of diameter variation, percent	4	4
Modulus of elasticity, psi	$29x10^6$	$29x10^6$
Yield strength, psi	$50x10^3$	$220x10^3$
Ultimate tensile strength, psi	$110x10^3$	$275x10^3$
Elongation in 2 inches, percent	11	1.5
Density, g/cm^3	7.9	7.9

Properties data for hard temper 300 filament yarn of various twists are tabulated below. Individual filaments are 15 microns in diameter and yarn diameter is approximately 11 mils (ref. 29).

Twist (turns/in.)	Avg. load to fracture (lbs)	Coeff. of variation of fracture load (percent)	Avg. Elongation (6 in. gage length) (percent)	Avg. U.T.S. (psi)
2	21.2	2.6	1.6	$256x10^3$
3	22.1	2.1	1.7	$266x10^3$
4	23.2	2.5	1.8	$278x10^3$
5	23.0	4.9	1.9	$277x10^3$

Brunsmet MF-Al yarn was exposed to high temperatures in air for 10 minutes at each test temperature. The effects on tensile properties of 270 filament yarn with a set twist of 10 turns per in. are tabulated below (ref. 29).

APPENDIX A - MATERIAL DATA SHEETS (CON'T.)

(Data Sheet No. 5) Stainless Steel, Alloy 304 (Con't.)

Temperature (°F.)	Avg. U.T.S. (psi)	Avg. Elongation (percent)
70	283×10^3	1.8
1000	256×10^3	11.6
1500	58×10^3	4.6
1800	28.5×10^3	3.7
2000	21.1×10^3	2.4
2200	11.9×10^3	1.5

Values for electrical and thermal properties for Brunsmet MF-Al are given below (ref. 10).

Electrical resistivity, ohm-cm	29×10^{-6}
Thermal conductivity, cal/sec/cm^2/cm/°C.,	1.1×10^{-1}

APPENDIX A - MATERIAL DATA SHEETS (CON'T.)

(Data Sheet No. 6) Aluminized Organic Films

General Information. - Aluminized organic films may be classified as follows:

(1) Laminates of aluminum foil and organic substrates

(2) Composites formed by vacuum deposition of aluminum on organic film substrates

(3) Aluminum loaded paints for application to organic film substrated.

Aluminum surfaces may be modified by anodizing or other treatment designed to produce α_s/ϵ ratios selected for thermal control.

Consideration should be given to surface treatments or coatings which will reduce ultrahigh vacuum adhesion (cold welding of metal surfaces in mutual contact) since aluminized films are candidates for use in the radiotelescope as reflector tapes and rim mass.

Properties. - Typical laminated composites are manufactured by Schjeldahl Corporation. GT-755 is a stock product composed of 2-mil Mylar* Type A and 1-mil aluminum foil (alloy 1145-0) bonded together with a thermosetting polyester adhesive (ref. 21). X-850 is a laminate composed of 0.25-mil Type S aluminized Mylar* 0.6 oz./yd.^{2} Dacron* scrim (12 by 2 leno weave) and 0.50-mil Type S aluminized Mylar*, bonded together with a thermoplastic polyester adhesive. In this construction the aluminized surfaces are exposed both sides and the scrim produces a textured surface (ref. 22). Properties data are tabulated below (ref. 21, 22):

	GT-755	X-850
Tensile Strength, lbs/in. of width,		
Machine direction	45	58
Transverse direction	45	45
Elongation, percent, machine and transverse direction	10	20
Weight, oz./yd.^{2}	4.7	1.65
Hook tear strength, lb. max.	-	110

* DuPont Registered Trademark

(Data Sheet No. 6) Aluminized Organic Films (Con't.)

(Con't.)	GT-755	X-850
Thickness, mils	4	7
Service Temperature, °C.	-60 to +110	-100 to +135

Samples of aluminized Kapton* film have been received by Astro Research Corp. These composites were produced by National Research Corp. using vacuum deposition techniques. Although the materials have not yet been tested, they demonstrate the feasibility of this process. Nominal thickness data for the two samples are:

	Sample 1	Sample 2
Sides aluminized	1	2
Kapton* film thickness, mils	0.50	1.0
Aluminum thickness, mils		
Side A	0.25	0.25
Side B	none	0.25
Total composite thickness, mils	0.75	2.0

The ratios of solar absorptance (α_s) to emittance (ϵ) are listed below for several representative aluminized materials.

(1) Polished aluminum as used on Alouette: $\alpha_s/\epsilon = 2.5$ (ref. 2)

(2) Anodized aluminum as used on Alouette: $\alpha_s/\epsilon = 0.95$ (ref. 2)

(3) Alodine 401-45, an amorphous compound consisting mainly of chromium and aluminum phosphates of thickness 0.2 mil was used on Echo II (ref. 2).

(4) MTL-3, an adaptation of Alodine 401-45 was used on Pegasus: $\alpha_s/\epsilon \sim 1.0$ (ref. 2)

(5) Plain aluminum foil, MIL-A-148C without substrate: $\alpha_s/\epsilon = 3.0$ (ref. 23).

(6) Aluminum foil, rubber based adhesive backed (fasson foil) with any substrate: $\alpha_s/\epsilon = 3.0$

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(Data Sheet No. 6) Aluminized Organic Films (Con't.)

(7) Aluminum foil, silicone-based adhesive backed (Mystik 7402) with any substrate: $\alpha_s/\epsilon = 3.0$ (ref. 23)

(8) Reynolds Wrap foil, smooth: dull side $\alpha_s/\epsilon = 5.0$, shiny side $\alpha_s/\epsilon = 6.3$ (ref. 23).

(Data Sheet No. 7) Fiber, Composite, Aluminum Coated Fused Quartz

General Information. - Continuous fibers of fused quartz, or silica (SiO_2), have been coated with aluminum by Rolls Royce Research Laboratory of Derby, England. The process is proprietary but has been studied by Hughes Aircraft Co. Preliminary arrangements have been made for licensing the process and for use of existing manufacturing equipment.

The composite fibers are proposed for use in fabricated tape form as antenna mesh (ref. 13).

Properties. - Some properties of the aluminum coated silica fibers are tabulated below (ref. 13):

Diameter of silica	50 microns standard (25 to 100 microns available)
Thickness of coating	0.4 times radius, giving equal area of metal
Coefficient of thermal expansion	0.5×10^{-6} per °F
Tensile strength in air (aluminum coat)	620,000 lb/in^2 (on fiber) 320,000 lb/in^2 (overall)
Static fatigue strength in air (aluminum coat exposed 1 to 2 months)	200,000 lb/in^2 (on fiber) 100,000 lb/in^2 (overall)
Tensile strength after 1 to 2 months immersion in water (aluminum coat)	Falls by 40 percent
Density	Overall 2.45 gm/cc (aluminum coat)

NOTE: Fibers exposed to moisture regain their strength after drying.

(Data Sheet No. 8) Tubing, Composite, Kapton*/Boron/Epoxy Resin

General Information. - An experimental quantity of composite tubing has been fabricated and tested by Astro Research Corporation.

The components are:

(1) Kapton* Type H Film - E. I. DuPont de Nemours.

(2) Elemental boron vacuum deposited on one side of the film - National Research Corporation.

(3) Epoxy laminating resin system used to bond the formed tube:

(a) Epon 815 - Shell Chemical Corporation.

(b) Versamid 125 - General Mills.

The composite tubing is proposed for use as longerons and other structural elements of the deployable mast.

This material is not presently available as a stock item due to its experimental status.

Properties. - Principal advantages of the composite tubing are that it possesses a high modulus of elasticity and low density. Calculations have shown that its theoretical modulus to density ratio should be about twice that of aluminum tubing in a similar size. Tests on laboratory prepared samples have yielded ratios equal to those for aluminum tubing and it appears highly probable that values approaching the theoretical can be attained with appropriate modifications in design and fabrication technique.

Data given below are typical of the results obtained on laboratory prepared specimens (ref. 12).

Kapton* film thickness	0.00055 inches
Deposited boron thickness	0.00025 inches
Epoxy resin thickness, approximate	0.0006 inches
Tubing wall thickness, approximate (5 film layers)	0.0014 inches
Tubing mean diameter	0.516 inches
Tubing specific weight	0.047 lb/in.^{3}
Tubing modulus of elasticity (measured in bending)	5.8×10^{-6} psi ± 10%

*DuPont Registered Trademark

APPENDIX A - MATERIAL DATA SHEETS (CON'T.)

(Data Sheet No. 9) Rod, Fibrous Glass Reinforced Epoxy Resin, Aerostrand Monostrand*

General Information. - Aerostrand Monostrand is manufactured by Owens Corning Fiberglas Corp., Toledo, Ohio.

Proposed applications are mast diagonals and tension tapes provided this material can be manufactured in tape form.

Proposed applications are:

(1) Longerons and other structural elements of the deployable mast.

Data given here are for composite rod, circular in cross section, which consists of an epoxy resin matrix heavily reinforced with fibrous S-glass. The reinforcement is laid in a helical pattern along the axis of the rod. Rod with longitudinally oriented reinforcement has also been produced and this configuration, together with other construction variations, will probably be available in the near future.

This material is presently in the development stage and cost data given here are not valid for volume production. A typical current quotation is as follows (ref. 8):

Volume:	Min. Break Strength:	Diameter:	Lot Price:	Availability:
2000 ft	440 lb	0.045 in.	$ 120	Immediate
2000 ft	1200 lb	0.075 in.	$ 200	Immediate
2000 ft	1700 lb	0.090 in.	$ 500	30 days
2000 ft	3000 lb	0.120 in.	$1000	60 days

Properties. - Physical and mechanical properties typical for 440 lb minimum break load material are tabulated below (ref. 9):

* Owens Corning Trademark

APPENDIX A - MATERIAL DATA SHEETS (CON'T.)

(Data Sheet No. 9) Rod, Fibrous Glass Reinforced Epoxy Resin, Aerostrand Monostrand* (Con't.)

Minimum Breaking Load	490 lb @ -65°F., 100% R.H. 440 lb @ 72°F., 50% R.H. 420 lb @ 72°F., 100% R.H. 420 lb @ 150°F., 5% R.H.
Tensile Modulus	7.0×10^6 psi @ 72°F., 50% R.H.
Elongation at Break	5% @ 72°F., 50% R.H.
Diameter	0.045 in. ± 0.003 in.
Minimum Bend Radius	3/8 in.
Specific Gravity	1.93 ± 0.17
Weight per Thousand Feet	1.21 lb ± 0.14 lb

The manufacturer has devised systems for splicing and for the attachment of terminations using standard parts. 440 lb rod terminated with Fork End Cable Terminal MS 2066-7-6, modified (available from American Chain and Cable and Bergen Wire Rope) has a tensile efficiency of 100%. The rod spliced with American Chain and Cable Splice Package RAA-7066 has a tensile efficiency of 95% (ref. 9).

The results of stress moisture tests on Aerostrand Monostrand are depicted graphically below (ref. 9).

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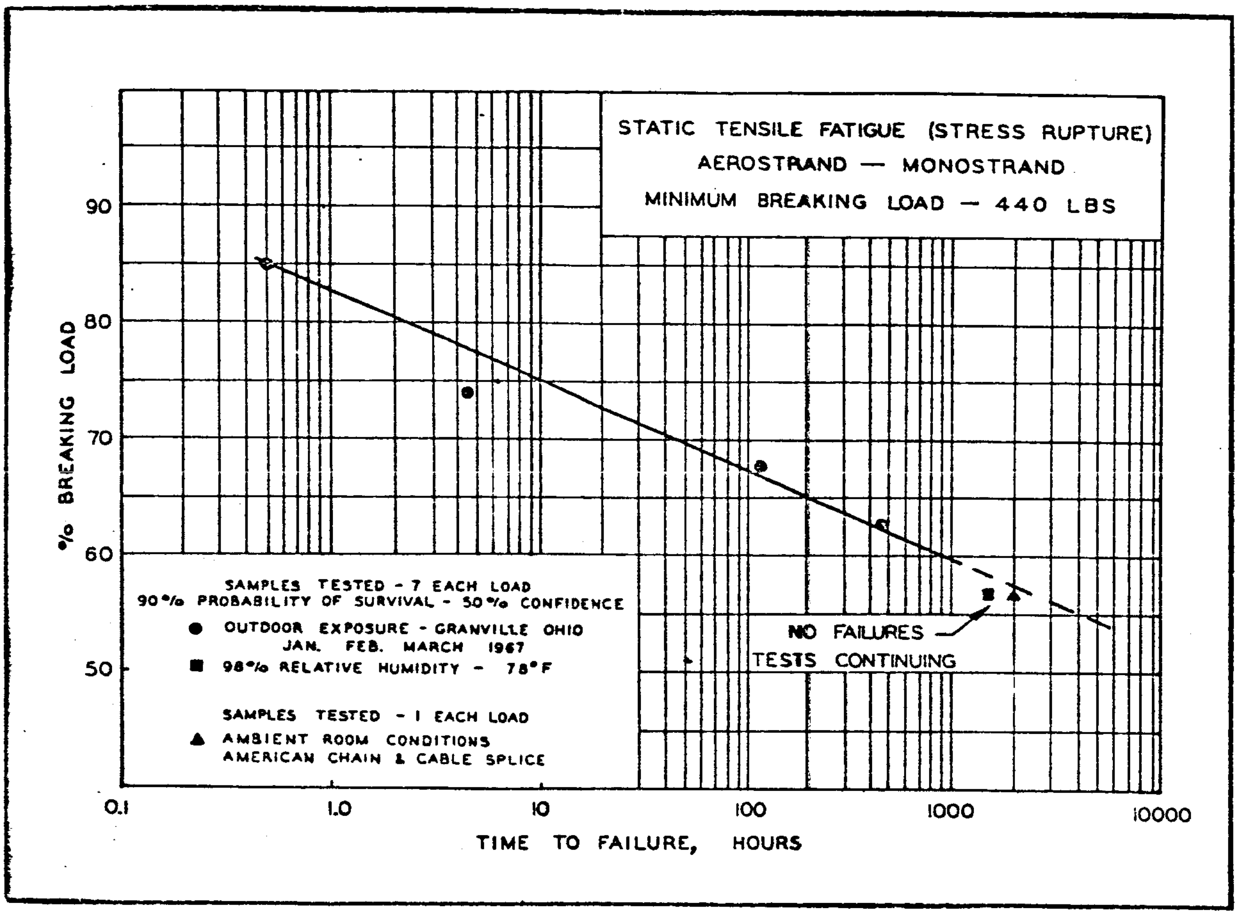
* Owens Corning Trademark

APPENDIX A - MATERIAL DATA SHEETS (CON'T.)
(Data Sheet No. 9) Rod, Fibrous Glass Reinforced Epoxy Resin, Aerostrand Monostrand* (Con't.)



The coefficient of thermal expansion has been estimated as "markedly lower" than 5 to 15 $\times 10^{-6}$ in./in./°F.

* Owens Corning Trademark

(Data Sheet No. 10) Magnesium Alloy M1A

General Information. - Magnesium alloys are available as extruded tubing in several grades. Alloy M1A is representative in its properties and is an attractive candidate for use as longerons and other structural elements of the mast since it is light in weight, possesses desirable mechanical properties, is relatively corrosion resistant, and lends itself well to welding and other conventional fabrication techniques (ref. 16).

Properties. - Typical physical properties of Alloy M1A are tabulated below (ref. 16):

Specific gravity, g/cm^3	1.76
Specific weight, lbs/in^3	0.064
Melting temperature, °F	1200
Electrical conductivity at 20°C (68°F), percent of IACS	34.5
Electrical resistivity at 20°C (68°F), microhm-cm	5
Thermal conductivity at 212°F to 572°F, cal/cm/cm^2/°C/sec.	0.33
Thermal expansion at 68°F to 212°F, micro-in/in/°C	26

Mechanical properties of Alloy M1A in tubing form are as follows (ref. 16):

Modulus of elasticity, psi	6.5×10^6
Modulus of rigidity, psi	2.4×10^6
Poisson's ratio,	0.35
Tensile strength, 0.2% offset, psi	35×10^3
Tensile yield strength, psi	21×10^3
Elongation, percent	9
Brinell hardness, 500 kg load, 10 mm ball,	42
Rockwell E hardness,	41
Compressive yield strength, psi	9×10^3

(Data Sheet No. 10) Magnesium Alloy M1A (Con't.)

Typical tensile properties of Alloy M1A extrusions at elevated temperatures are as follows (ref. 16):

Test Temperature (°F)	Tensile Strength (psi)	Yield Strength (psi)	Elongation (percent)
70	37,000	26,000	11
200	27,000	21,000	16
250	24,000	19,000	18
300	21,000	16,000	21
400	17,000	12,000	27
600	9,000	5,000	53

The chemical composition of Alloy M1A is tabulated below (ref. 16):

Constituent	Nominal Composition (percent)	Composition Limits (percent)
Manganese	1.2	1.2 min.
Calcium	0.09	0.04 to 0.14
Total other	-	0.41 max.
Magnesium	remainder	remainder

Weldability ratings for Alloy M1A are listed below (ref. 16):

Welding Method	Rating
Helium or argon arc	excellent, preferred
Oxyacetylene	in general use
Resistance	in general use